MODERN MEASUREMENTS

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Measurements today deal with new quantities whose units are not simply those of length, mass and time. To measure these new quantities science has developed new instruments, working on new principles.

Standards

Any measurement, in its final form, depends upon comparison with some carefully chosen standard. In medieval England, the ancient standard of volume, the bushel and the gallon, were preserved in the safest place in the realm—the underground Chapel of the Pyx in Westminster. Modern standards are guarded no less religiously. Electrical quantities such as resistance and voltage, which possess no visible characteristics, depend for their very existence upon a set of fixed standards.

The standard for voltage is a sealed glass tube containing a specified chemical solution. This standard cell produces a potential, about one volt, which remains constant at a given temperature. The problem of obtaining a standard voltage is, therefore, one of maintaining a constant temperature. The temperature of the standard cell has been fixed at 25°C. To keep the cell at this temperature it is mounted in an oil-filled tank. Electric heaters warm the bath and a motor-driven stirrer provides circulation. A temperature change as small as 1/1000 of one degree centigrade is sufficient to unbalance a control circuit, which, working in connection with a relay system, changes the amount of current flowing through the heaters and again adjusts the bath to the standard temperature. This regulation does not permit a voltage shift of more than one-millionth of the normal value of the cell. Resistance standards also require temperature control by a similar method.

Electric measurements are so precise that measurements of time by conventional clocks are, in many instances, inadequate. Instead, electric circuits, vacuum tubes, and quartz crystal oscillators produce an accurately controlled alternating current which drives synchronous electric clocks—clocks accurate to within one minute in two years.

The maintainance of electrical standards depends largely upon temperature control. Standard thermometers and thermocouples cover a wide range of temperatures (319 below zero, Fahrenheit, to 2732 above) which are standardized at numerous fixed points: the temperature of liquid oxygen, of ice, of steam, of sulphur vapor, and the freezing points of tin, lead, zinc, aluminum, silver and copper.

About thirty years ago a variety of tungsten was developed which stimulated much research in the higher temperature bracket. Tungsten melts at the extremely high temperature of 6119° Fahrenheit, well up toward the highest temperatures attained by man. Researches on tungsten have produced a temperature scale of such accuracy that practically all high temperature measurements rely upon it as a standard.

Meters and Instruments

Leading engineering societies have drawn a distinction between the two classes of measuring devices, meters and instruments. An instrument is a measuring device that indicates the momentary value of the quantity being measured. If that value fluctuates with time the meter reading varies with it—dropping to zero when the quantity falls to zero. A meter, on the other hand, sums up, or integrates, all of the quantity passing through it, the reading of the meter being an indication of the total sum passing through the meter. For example the watthour meter, located somewhere in your basement or attic, keeps count of the electric energy used by your lamps and electric appliances. Day in and day out your meter watches over the flow of electricity assuring you that you get the current you pay for.

Scientists require current-measuring devices for a few millionths of an ampere. For them there is the microammeter. Manufacturers want to measure currents of 100, 1000, or 10,000 amperes. For this purpose switchboard instruments, complete with accurately calibrated shunts, are made available. Power companies need instruments such as wattmeters, frequency meters, power-factor meters—single-phase and polyphase, indicating and recording.

The complicated array of instruments can, however, be classified according to the principle upon which they operate. These principles—d'Arsonval, magnetic-vane and electrodynamic—permit ingenious variations of built-in circuits covering a wide range of applications.

The d'Arsonval instrument has been used for years in measuring direct current. A light coil of fine wire is so mounted on pivots as to be free to rotate. Pole pieces of a strong permanent magnet surround this armature coil and a soft-iron core within the armature concentrates the magnetic field at the region of the coil. When the current to be measured flows through the movable coil, it produces a magnetic field that interacts with the field of the magnet as the coil rotates. The force producing rotation is proportional to the current and is opposed by a spiral spring which provides a constant countertorque. The deflection of the pointer, which is fixed to the coil assembly, is proportional to the current in the coil.

The magnetic-vane instrument is used for measuring voltage and current in alternating circuits. Electric current passes through a stationary field coil producing a magnetic field. In the axis of the coil is mounted a shaft carrying a thin vane of soft iron, or like material which does not become permanently magnetized. The vane tends to line up with the field produced by the coil; the pointer mounted on the shaft travels across the scale—a spiral spring controls the motion.

The electrodynamic principle can be adapted to meet a variety of apparently different requirements. As in the magnetic vane principle the field is supplied by fixed coils. But now the moving element is also a coil carrying a current. The interaction of the two magnetic fields produced by current flowing through the two coils determines the deflection. In a wattmeter, where the quantity to be measured is the product of current and voltage-in-phase, one coil assembly produces a field proportional to voltage while the other produces a field proportional to the current. The meter performs the mathematical operation of multiplication.

The recent development of "Alnico", an alloy of unusual magnetic strength, has led to the improvement of the d'Arsonval instrument. This new instrument, called the concentric-magnet instrument, consists of a soft-iron ring which completely encircles two Alinco magnets or pole pieces. Between the two magnets are the moving coil and magnetic core. This instrument has the advantage of being smaller in size, lighter in weight and in addition combines high sensitivity with excellent shielding from the effects of stray magnetic fields.

Production

Armed with these fundamental facts we are ready to investigate some of the intricacies of the construction of the instrument. In story-book fashion let us follow the development of a typical precision instrument. If we sometimes lose the thread of the story, it is because unfamiliar sights meet our every glance, because of the thrill of intense accuracy, because romance greets us at every turn.

Plans and preparations for the construction of a precision instrument are begun far in advance. Special shellac is prepared two years before any move is made toward assembly. These two years of storage in a darkened room have given the shellac rare and subtle properties. While this mellowing process is taking place special bronze is cast, its composition controlled by accurate analysis. The cast bronze ingots are drawn into wire which is tested and stored for future use in the making of springs.

Accuracy in the control spring is important. The torque exerted by the finished spring varies as the cube of the thickness; doubling the thickness increases the torque eight times. To keep well within the elastic limit of the metal the ratio between the length and thickness must be more than 2500 to one.

The bronze wire already described is passed again and again between powerful rolls—rolls that have received their polish with the care and precision given an astronomical telescope. With each pass the thickness of the bronze cord is reduced by 5/10,000 of an inch. The final ribbon is uniform within the limits of measurement because the rolls are as perfect as engineering skill can make them. The delicate strips, often thinner than a human hair, are trimmed to size and wound in exacting spirals. The springs are then placed in the tempering furnace where they are under constant supervision in order that life-long mechanical rigidity will be instilled in them.

An operator with tweezers places each spring upon a torsion-measuring device which determines the amount of torque it will exert. The springs are classified by the torque they exert in order that the engineers' specifications will be exactly fulfilled.

The value of a delicate measuring instrument, such as a microammeter, would be lost if it abstracted much power from the circuit. Some standard instruments require less than 5/10,000 watt for full-scale deflection. In order to achieve negligible power consumption the weight of moving parts must be kept in strict minimum, yet construction must be sturdy enough to withstand jars and jolts. To meet these almost paradoxical requirements jeweled bearings are incorporated into every fine instrument. The jewels used in these pivots are tiny sapphires. In each sapphire is cut a cuplike depression with a taper slightly more blunt than that of the pivot it is to receive. The jeweled bearing is examined under a high-power microscope when it comes from the jewel cutters; after mounting a sharpened point of lead is forced into the tapered depression making an exact reverse of the cavity. When the enlarged image of the lead point is projected on a screen any flaws in the bearing surface are immediately detected.

The pivots which turn in the sapphire bearings are made of hardened steel. The polishing of the turning surface of the pivot is a task that must be performed by hand. The finished point is much sharper than the finest needle, and the end is rounded so that its radius of curvature is not less than 75/100,000, and not greater than 15/10,000 inch—not greater than half the diameter of a human hair. The area of the point supports the whole weight of the moving mechanism. This weight, many times no more than a fraction of a gram, is small, yet the pressure on the infinitesimal bearing area may be thousands of pounds per square inch. As in the building of bridges or a great building the design of instruments requires a detailed knowledge of stresses and the strength of materials.

The production line of a precision instrument is unique in its "candy-kitchen" cleanliness. Operators are required to wear white starched uniforms to prevent dust and lint from becoming sealed in the instrument. As the instrument passes these deft-fingered artisans each adds, without lost motion, the touch required of him. Incoherent parts become living mechanism.

Accurate reading of an accurate instrument is assured by a pointer placed in the same plane as, and almost touching, the scale. In the calibration of this scale each instrument is compared with a calibrated standard, and through photographic processes the scale for that particular instrument is provided. As a further convenience slightly etched antiglare glass is used to cover the face of the instrument. All joints are dust-proofed.

The manufacturer attempts, by rigorous tests, to discover any weakness that might appear in his instrument. These tests are conducted in temperatures ranging from sub-zero to well over 100 degrees Fahrenheit and in humidities up to 100 per cent. Fulfillment of these unnatural requirements guarantees an instrument that will meet the severest tests ordinary service can offer.